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Sustainability assessment of renewable energy projects for off-grid rural electrification: The Pangan-an Island case in the Philippines

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ABSTRACT

Renewable energy systems (RESs) have been promoted for rural electrification as an answer to the growing energy needs of communities while simultaneously satisfying environmental and resource scarcity problems. These off-grid systems however have several challenges in the perspective of sustainability due to the technically and financially weak recipients and users of the projects. There is still, however, less detailed understanding how the technical and economic aspects of the projects can properly match the social aspects to promote sustainability. This paper aimed to further understand the challenges and social impacts of rural electrification projects using RES through a case study of a centralized off-grid solar plant in the Philippines. The study used multiple correspondence analysis (MCA) to identify essential user attributes which explain the users' electricity consumption behaviors. The community cooperative had difficulties maintaining the facility in the long term due to financial and capacity related challenges. A holistic approach dealing with the technical, economic and social aspects in developing RES projects promote sustainability.

Contents

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1. Introduction

Reliable and affordable energy is required to meet the Millennium Development Goals (MDGs). Energy access in general relates quite well with poverty, where most of the poor are located in the rural hard to reach areas [1]. Rural electrification therefore may be considered the frontline of energy access and development, entailing much of a country's efforts and resources to sustainably provide [2]. Along with providing energy access for the underdeveloped areas, the use of clean energy to mitigate climate change has also become significant. The application of renewable energy systems (RES) in rural electrification has been perceived as the most promising clean and sustainable solution to the energy access challenge. However, several challenges are there for renewable energy systems such as high cost and technological complexities. Due to these challenges, there is a great need to properly monitor the sustainability of these projects. Recent studies have incorporated a holistic approach in assessing the sustainability of these projects. Sustainability best shows itself only through time and there are however few studies of projects which have been in service for a considerable length of time to clearly define what is sustainable in the long run.

The purpose of the study is to further understand and promote awareness of the challenges and social impacts of rural electrification projects using RESs. The specific objectives of this study are twofold: (a) to perform a sustainability assessment of an existing RES project in an off-grid small island application (Pangan-an Island Solar Project), and (b) to investigate user factors intrinsic of off-grid rural communities which affect the sustainability of electrification projects. A case study of the Pangan-an Island Solar Electrification Project in the Philippines was conducted. Investigating the project at its mid to end of life provide insights on longer term challenges of the community which directly relate with project sustainability.

2. Investigating the sustainability of renewable energy systems for rural electrification

2.1. Renewable energy systems for rural electrification

Rural Electrification is directly related to poverty and development. With developments in technology and increasing fossil fuel prices, RESs have often been considered as the optimal means of delivering electricity to rural areas not connected to the grid [3]. RESs have advantages such as: faster procurement, sometimes more economical than grid connection, and clean for the environment. RESs also have down sides such as high cost for poor communities and technological complexities which have caused sustainability issues. To date, conventional sources such as kerosene lamps and fuel-based electric generators, often times more economical and accessible for people, are the most common sources of power for rural communities. However, with the thrust to promote clean and sustainable energy, efforts have been enhanced to improve the quality of power through RESs in spite of the apparent challenges. Among the rural electrification projects developed, only a few are however comprehensively monitored and studied for sustainability after installation. On top of the technical and economic challenges emphasized by studies, social factors were also found important to consider in these projects [4,5]. And yet, these could be the most difficult to measure and control. As a result, failures are generally indicated as a certain mismatch with the people and the project, leaving electrification efforts unable to spur development. These mismatches and causes of failure, however, need further understanding. There is a distinct difference in energy that improves living conditions, such as lighting, and energy that enables productive activities. Only with the latter will economic and social transformation occur. There is a general tendency that once electrified, majority of the electricity consumed is used for lighting and only a fraction is utilized for productive uses [6,7]. Thus, the amount, reliability and usage of power provided by RESs have to distinctly cater to the community's needs. According to UNDP, capacity development, defined as an extensive process of strengthening an individual or organizations to reach objectives sustainably, is also essential in developing rural energy access [8]. There is, therefore, a need to holistically consider the components and impacts of RES electrification projects being a medium of social transformation.

2.2. Pangan-an Island Solar Electrification Project

Pangan-an island is a small rural island located 45-min offshore of Cebu Island in the Philippines. The island has a current population of about 2800 people with fishing as the only prominent industry for the community. Back in 1999, the Belgian government donated PhP22M to install a centralized solar plant. This project is dubbed as the first centralized solar project in the Philippines. Before the project, the people in the island used kerosene lamps and diesel generators for electricity. The project brought light designed for about 300 households in the island. There was hope in realizing that the 24-h electricity would enable the community to develop and improve the community's circumstance. Along with the creation of the plant, a community cooperative, Pangan-an Island Community Cooperative for Development (PICCD), was formed to maintain the PV plant especially for the collection of user fees mainly for the future replacement of the batteries. According to a study by Quitoriano [9], the cooperative showed weak financial flow in the early stages of the project due low collection efficiency and few user connections. The cooperative remained dependent on external technical support while financially the people found it difficult to pay the high cost of the PV service. A study conducted by Shiota et al. [10] investigated the technical components of the system and showed that the system initially had inferior quality PV panels which would further contribute to a faster decline in efficiency of the system. About 12 years after installation, there is merit in revisiting the project and whether the targets set by the proponents have been reached. There is also an apparent need to further understand the social aspects of the project which were not thoroughly investigated by previous studies. The importance of the investigation extends beyond the boundaries of the project, such that this

type of rural island scenario is common in the Philippines and other developing countries.

2.3. Assessment framework review and development

An extensive review of sustainability assessment frameworks was conducted. Among many frameworks and amidst the lack of a standardized assessment methodology, five (5) aspects stood out as commonalities: Technological, Economic, Social, Environmental, and Institutional [4,11,12]. In reference to the previous studies of Pangan-an island, which mainly focused on institutional and technical aspects, this study focuses on the social aspects of the project while catering to a holistic sustainability approach. The study framework then discusses two (2) aspects of investigation: techno-economic and socio-economic. These aspects showed good relevance to explain the social factors which contribute to project sustainability. Economic discussions were merged with technological and social aspects due to their intrinsic commonalities. For example, one could not comprehensively compare technologies without considering costs while the improvement of people's lives almost always includes economic progress. To compliment the analysis, rural electrification indicators were used. There are noteworthy indicators for rural electrifications discussed by Ilskog [12]. Examples of sustainability indicators for rural electrification are as follows: share of electrified households using electricity for income-generating activities (economic), share of population with electricity access (social), and share of electrified households where electricity has replaced other energy sources of lighting (environmental). Also essential to sustainability, capacity development aspects were considered. In this paper, capacity development referred to processes which enhanced the abilities of individuals in the community, end-users level, and plant management level to sustain the plant and activities by themselves.

Data for the study was collected using two ways: (1) interviews with cooperative members, project development staff, and technical consultants and (2) questionnaire survey for cooperative members. For the survey, hereinafter referred as 2010 Survey, 50 randomly selected users among the total 236 PV users were interviewed by the research team using a questionnaire survey (12.33% confidence interval) consisting of questions about: household information, electricity usage, socio-economic status, and perception of the project and management. The social aspects relating to the usage of electricity and conditions of the users were analyzed for correlations.

In order to further investigate the relationships of the collected social and economic characteristics of the users in the island, multiple correspondence analysis (MCA) was used. This particular analysis allows comparative analysis for categorical data, which for this case study is quite evident. Multiple correspondence analysis (MCA), which is an extension of correspondence analysis (CA), is an exploratory multivariate method capable of graphical and numerical analysis of data matrices containing variables which are measurable in ordinal and nominal scale. MCA has been applied in various fields including economics and social sciences. Applying MCA for social aspects of a rural electrification scenario is also novel for this paper. For more detailed explanations of MCA, see [13,14]. The study used STATA 10 analytical software to perform MCA.

3. Analysis and results of the field investigation

3.1. Techno-economic aspects

3.1.1. Technical and cost specifications of power sources

The study investigated the specifications of the solar power system and the alternative power sources available in the island. The cost and capacity of each power source was calculated.

Table 1
PV system technical components and costs.

Components	Cost (PhP)	Life (years)
Solar panels (504 modules)	9,081,000	20
Batteries (118 units)	3,102,000	10
Battery control unit	408,000	5
Inverter	2,108,000	10
AC panel	217,500	10
Other components	3,809,250	
Total system cost	18,725,750	

Sources: [9,10].
Costs are at 1998 prices, where USD1 = PhP40.

3.1.2. The solar power plant

The solar plant was donated by the government of Belgium with a total grant of PhP22M on year 1999. The system was comprised of 504 PV modules with a combination of 80 and 90 W peak each totalling 45.36 kWp with 20-year life-spans. There were 118 battery units with 10-year life-spans (2-V cells and 1800 Ah), two inverters, AC panels, battery control unit, and other accessories to complete the system. The power output of the system was computed to be 85.5 kWh/day. The cost per kWh generated by the system was computed by equation, COE = (*capital* + *replacement* +*O&M*)/*TotalPowerGenerated*; where *COE* refers to the Cost per kWh of Energy of the PV system, *capital* refers to the capital cost, which for this case was a donation of PhP22M, *O&M* refers to the operations and maintenance including personnel, supplies and cooperative management, and finally *TotalPowerGenerated* refers to the total output of the system. The capital cost of components and plant cost totalled PhP18.725M as shown in Table 1 while the rest of the PhP22M budget went to the grid connection and project development costs. However, for the cost per kWh of PV, the capital cost was considered as zero since it is a donated system. The replacement cost was computed from the annualized cost for the batteries, control unit, inverter and AC Panel assuming replacement for every life cycle. The total plant life was assumed to be the PV panel life of 20 years. The replacement cost was calculated to be PhP624,350 per year. The O&M cost was calculated from the cost of personnel, supplies and transportation. This was estimated to be PhP252,000 per year as referenced from interviews and previous documentations [9]. Overall, the Donated PV System Cost totalled PhP28/kWh (USD0.7/kWh). If the system were not donated, incorporating the full capital cost of the system, the PV System Cost totalled PhP58/kWh (USD1.45/kWh).

3.1.3. Kerosene lamps

The main source of light for the island, prior to the Solar Project, was the kerosene lamp. Through interviews and previous documentations [9], the cost of using a kerosene lamp at night in year 1999 was about PhP3.00 for 2.5 hours of light per night. The cost amounts to PhP1.2 per hour of light which accounts for only the kerosene used in the process. Assuming a particular household would use the lamp for 30 days per month, the cost of using a kerosene lamp amounts to PhP90 per month. In year 2010, the cost of using kerosene is PhP5.00 for 2.5 h. The cost amounts to PhP2 per hour and with an assumed 30 days usage amounts to PhP150 per month. The increase in kerosene lamp usage cost was due to the increase in the cost of kerosene, about PhP35 per liter in 1999 and PhP55 per liter in 2010 in the island.

3.1.4. Privately supplied generators

Prior to the Solar Project, there were a few private electric generator suppliers in the island. Through interviews and previous documentations, the private suppliers charged PhP5.00 for using a 20-W light bulb for 4 h in a night [9,15]. This amounted to a power

consumption of 2.4 kWh/month, and assuming 120 h of light, costing PhP62.5/kWh totalling PhP150 per month for a household. In recent years, private generators once again have been used to cope with the decline in PV supplied power. In year 2010, private suppliers charged PhP25 for using 11-watt CFL bulb for 4 h. This amounts to a power cost of PhP568/kWh. The increase in generator usage cost was mainly due to the increase in fuel prices, about PhP40 per liter in 1999 and PhP60 per liter of gasoline in 2010 in the island.

3.1.5. Comparison of costs and merits of alternative power sources

The comparison of both costs and available power among different power sources in year 1999 and 2010 are shown in Table 2. The costs are derived from what users are charged for the respective power services. In year 1999, it is seen that the cost of PV system per kWh is cheaper compared to the cost per kWh of gen-sets. However, considering that the PV system is centralized and would need to have its cost shared among users, the PV system would require each household to consume higher energy and pay higher compared to using generator sets. Hence, the cost per household per month is much higher than a generator set. The PV system would however provide a 24-h service with higher power to use for multiple functions compared to kerosene and generator sets which could only provide light for limited hours. The impact of the donation halved the cost of PV compared to what it would have cost without donation. In year 2010, the costs of kerosene lamps and generator sets increased due to higher cost of fuel. As for the PV system, the cost to recover the system may have increased slightly due to personnel costs and replacements. However, as shown in Table 2, the cost of PV was lowered to a minimum of PhP50 per month per household. This socialized cost was adopted by the cooperative to accommodate the slow and low payment of users who could not afford the full costs of PV. The merits of the PV system are thus: higher power capacity, clean, safe, renewable, and reasonable cost/kWh compared to private generator sets. The demerits of the PV system are as follows: high cost per household, dependent on donation, and needs long term and stringent system maintenance.

3.1.6. PV system size and demand matching

A graph of the cost and power per household per month versus the number of households using the PV system is shown in Fig. 1. The costs depicted for PV relates to the costs needed to maintain and replace the batteries of the plant. The centralized PV system has a fixed monthly cost and hence as the number of users increases, the required cost per household decreases. From the 2010 Survey conducted, it was found that the average cost households are paying per month is PhP110. Since the total number of users is only 236 as of 2010, the actual cost per household per month to generate enough income to maintain the PV system would be PhP309. In order to maintain the PV system, where users are paying only an average of PhP110 per month, there theoretically needs to be about 660 users. According to a 2010 census in the island, there are only 375 houses in the island. With a similar trend as the cost, the power per household decreases as the number of users increases. From the 2010 Survey, the average power consumption per household is approximated at 6 kWh/month. With 236 users, the expected consumption per month in order to have enough income to maintain the plant is 11 kWh/month. With less efficient batteries and PV panels, the plant would no longer be able to produce that amount of electricity. Overall, with the plant size and output, the required power sales is too high for the demand in the island therein incurring a cost per household which is unaffordable and unsustainable for the community.

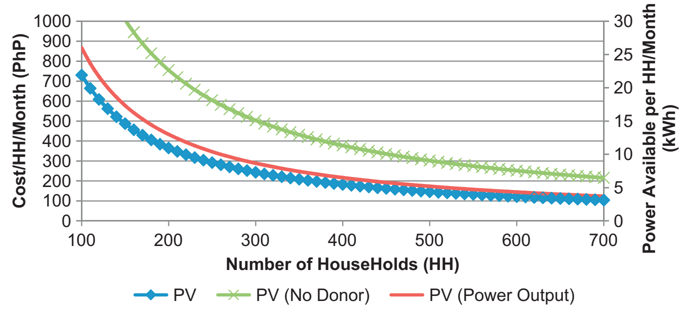

Fig. 1. Cost and power versus the number of households connected to the PV system.

3.1.7. Maintainability and reliability of the PV facility

Interviews with the plant manager and operations staff provided information regarding the current status of the plant. The PV Panels efficiency is lower than 70% and the battery system has low efficiency; where in technical sense it is considered “dead”. There has been no proper way of monitoring the output of the plant since the main plant meter has been out of service for over a year. With the batteries no longer able to store significant power, the hours with electricity are limited to only hours when sunlight is available, usually about 6 am to 6 pm for about 12 h of the day. During rainy or cloudy days, the PV system would not give off power for the users. According to a previous study by Shiota et al. [10], the components of the system were not of good quality to begin with and that replacements of the batteries and some PV panels were needed in about 7–10 years from the project start. A relatively high degree of technical know-how is required to install, operate and maintain the facility and this can be done through extensive training and capacity building. Through external technical support, this is achievable for the project. However, though the plant workers have been diligent in the regular cleaning and check-up of the system, since funds are not enough for battery and panel replacements, the system would eventually die out.

Table 2
Costs and power comparison of power source alternatives (1999 and 2010).

Power source	Hours of power (h/day)	Unit cost (PhP/kWh)	HH cost (PhP/month/HH)	Power/HH (kWh/month)
Year 1999 (USD1 = PhP39)				
Kerosene lamps	2.5	PhP3 per 2.5 h	90 (2.5 h/night for 30 days)	Unrated
Private generator sets	4	62.50 (PhP5 per 4 h)	150 (4 h/night for 30 days)	2.4 (20 W incandescent bulb for 4 h/night)
Solar PV system	24	28.00	243 (shared for 300 HHs)	8.55 (shared for 300 HHs)
Solar PV system (no donor)	24	58.00	504 (shared for 300 HHs)	8.55 (shared for 300 HHs)
Year 2010 (USD1 = PhP45)				
Kerosene lamps	2.5	PhP5 per 2.5 h	150 (2.5 h/night for 30 days)	Unrated
Private generator sets	4	568 (PhP25 per 4 h)	Sparingly used for entire month	1.32 (11 W CFL for 4 h/night)
Solar PV system	<12 (only time with sunlight)	15 (socialized cost)	50 (minimum to connect with PV)	<8.55 (low battery efficiency)

Exchange rates source: [16].
HH: household.

Table 3
Selected community and PV system information from years 1995, 1999, and 2010.

Variables	1995	1999	2010
No. of households in the Island	287	302	375
Population	1263	–	2875
Number of users of PV system	0	155	236
Percentage of households using PV system	0	51%	63%

Source: [9,15] and 2010 Survey.

3.2. *Socio-economic aspects*

3.2.1. *Pangan-an island community and PV users*

In order to further understand the community and PV users, a community survey was conducted. The users and community information are summarized in Tables 3 and 4. The statistics indicate that the PV users are mostly (58%) low-income households with an average of 5 members with fishing as a means of livelihood. Majority of the households have a single income earner with an elementary educational level. There are several households running businesses such as small stores, selling food, water and supplies, fish trading, video and karaoke rentals, and shell crafts selling. There are also service oriented occupations such as boat operation, tricycle service, and public/civil service. However, business or services were not directly related to using electricity to earn. The percentage of households using the PV system increased from 51% in year 1999, project start, to 63% in 2010. However, the initial target of 300 households connected has yet to be reached.

3.2.2. *Electricity usage of the community*

From the 2010 Survey, the usage type, amount, and time of use was characterized. Fig. 2 shows the type of usage of the electricity by the users. Light was the basic usage of electricity, which users claimed improved their activities in the island, extending people's working or operation time to the evening. Fishermen could work on their nets and children could study at night. There were more than 50% of users using TV sets, which they would use for entertainment and news. Fishermen found news important especially for weather warnings. The phone charger is a more recent type of usage as some individuals use mobile phones. There are also public facilities which have been able to make use of the power: school, health center, barangay (village) hall, and 18 street lights. These facilities also contribute to the power sales, though in a limited manner. There were some households which were able to use electricity for their businesses, such as small shops and supplies. However, these were very limited to a few users and no other economically significant industries were present in the island which uses electricity to make profit. The monthly power consumption per kWh is seen in Fig. 3. Most (42%) of the households are using only less than 3 kWh of power per month. The average usage per month was calculated to be 6 kWh. In 2005, the average consumption was about 9 kWh [10]. The decrease in consumption average may be attributed to the decrease in the power produced by the deteriorating plant and the increased number of lower income households connected to the plant due to lowered tariff rates. The time of electricity usage in a day is depicted in Fig. 4. Most of the users use electricity during meal times, which is during the 11 am to 2 pm time frame for lunch and the 5 pm to 8 pm time frame for dinner. More than 70% of usage is at the 5 pm to 8 pm time frame and thus electricity may deem to be most important during this time. Before the solar project, all of the users used kerosene or gas lamps for lighting; whereas after the solar project, the usage of kerosene or gas decreased dramatically as seen in Fig. 5. Other alternatives are generator sets, flashlights, and candles which serve as options when solar power is not available. With decreasing power production, however, the availability of electricity after sundown becomes scarce. Hence, the usage of alternative sources may gradually increase again. From the evidences, it could not be said that the community maximized the use of electricity for economic gains. The usage type, amount, and time of use all point out that the social benefits of electricity for the community are mostly for welfare and lifestyle improvement. Economic benefits for electricity were indirect through bettered

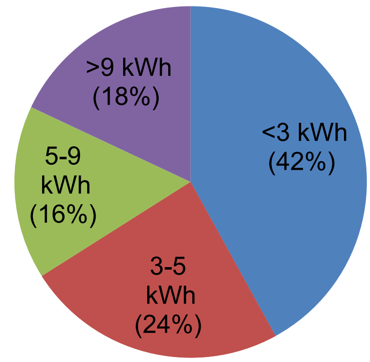

Fig. 3. Monthly power consumption of PV system users in kWh; from survey 2010 (n = 50).

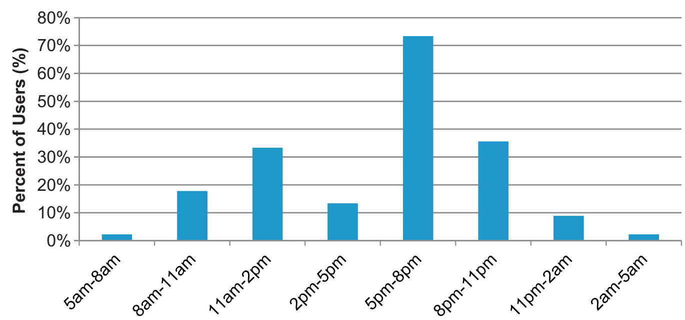

Fig. 4. Time of usage in a day of electricity from the PV system; from survey 2010 (n = 45).

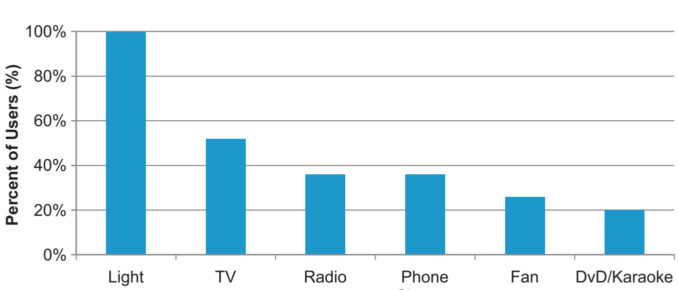

Fig. 2. Usage of electricity produced from the PV system; from survey 2010 (n = 50).

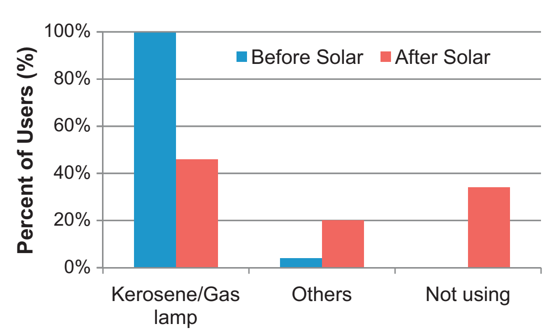

Fig. 5. Usage of alternative power sources, before and after the PV system; from survey 2010 (n = 50).

Table 4
PV system users' attributes; from 2010 survey.

PV user characteristics	(Average or %)	Std.	Min	Max	*n*
Age of household head	46.35	11.65	26	72	48
Education level					
Elementary level	65%				48
High school level	23%				48
College/vocational level	13%				48
Occupation					
Fishing	58%				50
Services (shell crafting, boat operator, etc.)	18%				50
Business (small stores, goods trading, etc.)	30%				50
Number of household members	4.96	1.70	1	10	50
Number of minors	2.46	1.49	0	6	50
Number of minors studying	1.82	1.39	0	5	49
Number of years connected to PV	9.32	2.87	2	12	44
Monthly household income	4752	3162	2000	18,000	50
Monthly household expenses	4135	2242	0	14,000	50
Number of income earners	1.20	0.41	1	2	49

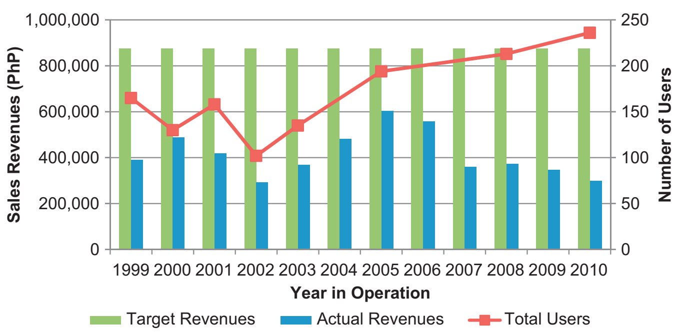

Fig. 6. Yearly electricity sales (target and actual) and the number of users connected to the PV system.

lighting. This emphasizes a need to introduce better capacity development measures in the end-user level which expand their business opportunities and know-how.

3.2.3. *Affordability and cooperative financials*

In order to consider the affordability of the power by the users, plant financials, pricing mechanism and the expenditure data of users were collected. The plant revenues, target and actual, are seen in Fig. 6. The target revenue is defined as the electricity sales which would cover for maintenance and replacement costs of the PV system while actual revenues refer to electricity sales that the users actually paid for the year. The data was taken from the financial reports of the cooperative, PICCD. In the first year of plant operations, users were required to pay a minimum charge of PhP210 for a consumption of 9 kWh (about PhP23.33/kWh) and PhP30/kWh exceeding that amount. With this price scheme, users found it hard to pay the minimum fee. For the initial years, the plant collections and user connections were generally low and thus the price had to be adjusted to encourage users to connect and pay. Table 5 shows the price adjustments, which took place over the years. The minimum charge was reduced to PhP150 from 1999 and still people would claim that they could not afford the tariff. There was an increase in connections from 2002 when the monthly

Table 6
Selected household financial data of the PV system users.

Household financials (average monthly)	Amount (PhP)
Cost of power from PV System	110
Cost for previous power source (prior to PV usage)	136
Cost of additional power source (simultaneous with PV)	182

minimum cost was reduced to PhP110. In 2005, revenues peaked due to stricter implementation of on-time payments, such that late payers would be cut in a few weeks' time. In 2006 however, the plant efficiency started to become low, such that not all users could reach the required 9 kWh minimum per month. Hence, there needed to be another restructuring of cost and collection system. From 2007, the minimum charge was set to PhP50 and the cost per kWh was at PhP15. Generally, as the minimum price per month was decreased, the number of users increased, spreading the social benefits of electricity. This indicates that many households in the community wish to connect with PV but could not afford a high monthly minimum. Despite increasing users, the actual revenues still could not reach the target revenues to properly maintain the plant. Interestingly, the average household cost of power prior to having PV is higher compared to the cost of power from the PV system per month, shown in Table 6. It is also notable that about 64% of users are using additional power sources simultaneously with PV which costs more per month than PV power. Hence, even if the users refuse to pay higher than the original minimum cost of PhP210, currently, many users are paying even more than that for simultaneously using PV and alternative sources of power. Evidently, as the users refused to pay the designed cost of the plant, the socialized price proved to be detrimental to the plant sustainability.

3.2.4. *Users' satisfaction levels of the PV project*

The users' satisfaction levels of several aspects of the project were taken through the survey. Fig. 7 shows the results; where a score of 1 means low satisfaction and a score of 5 means high satisfaction. There was an even distribution of satisfaction for the availability of electricity, amount of electricity and the affordability. This depicts the variation of users in terms of their amount needed

Table 5
Pricing structure for the PV system through the years.

Year	Minimum monthly consumption allowed (kWh/household)	Minimum monthly cost (PhP)	Charge per additional (PhP/kWh)	Effective price/kWh (PhP/kWh)
1998	9	210	30	23
1999–2002	7	150	30	21
2003–2006	9	110	23	12
2007–2010	3	50	15	15

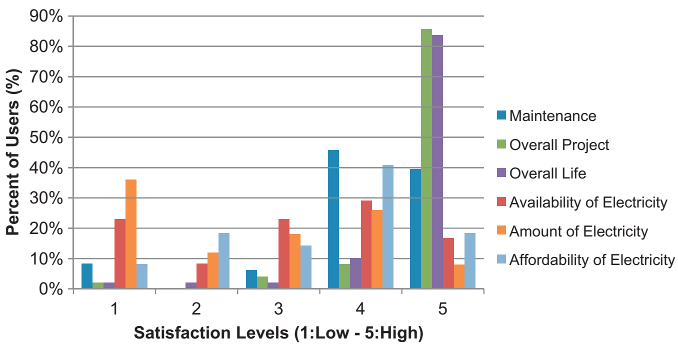

Fig. 7. Users' satisfaction levels for the PV system; from survey 2010 ($n = 50$).

and capability to pay. In general, the users were satisfied with the maintenance of the system, overall project, and their overall life in the island. When the users were asked to rank their needs among the essentials in daily life, electricity was ranked second among 8 items, shown in Table 7. The people thus had a positive impression of the project. The users also regard electricity as an important commodity in their daily lives.

3.2.5. *Plant cooperative and management*

The Pangan-an Island Cooperative for Community Development or PICCD is composed of the users of the PV system and is represented by a board of directors. The PICCD holds annual general assemblies where dialogues and workshops are set to discuss the financial, technical and managerial aspects of the PV plant. In terms of financial management, the plant has proper documentation of financials, as manifested by the yearly financial reports prepared by the PICCD board. There were also capacity development activities such as workshops and trainings for the board and management group of the plant at some point in the project. For the technical aspects of the plant, the PICCD regularly coordinates with its consultants such as the Philippine Department of Energy (DOE). The previous study in 2001 characterized the cooperative as internally dependent on the voice of a few major influential people, land owners, and externally dependent on the consultation group [9]. The internal and external dependence indicates managerial challenges and weaknesses. One indicator is that for more than a year, the main meter of the plant has been out of service. This equipment allows the management to determine the amount of electricity produced. Until now, the main meter has not been replaced even if there are funds to do so. This indicates that the management perceives the plant as deteriorating and therefore only little can be done about it. The effects of the weakness of the cooperative can also be seen in its inability to impose the proper collection and fines on the users. The financial health of the organization goes back to the financial health of the people, where if the people pay properly, the financial needs of the plants can be addressed. Several measures have been taken to improve the revenue stream of the plant such as price adjustments and stricter collection penalties. These efforts however were not enough to improve electricity sales and collection. There were also some attempts by the cooperative management to engage in social venture activities to create additional funding for the cooperative and livelihood in the community. However, these were short lived endeavors.

The cooperative, in cooperation with an external research group, is currently developing a system to use rechargeable lamps to augment the inefficient plant batteries and once more provide light at night. Rehabilitation and support projects such as these could be good for the project. However, the success of rehabilitation endeavors would evidently depend on the capability of the cooperative management and the support of the users. PICCD as an institution does have its merits as being properly organized with the proper bylaws and policies to run the activities of the plant. However, more capacity development efforts to augment the technical and management abilities of the plant cooperative are needed. These efforts are however costly and need external support.

Table 7
Ranking of PV system users' needs.

Users' needs	Rank
Food and cooking	1
Electricity	2
Health related	3
Education	4
Housing	5
Clean potable water	6
Transportation	7
Others	8

4. Understanding users' attributes using MCA

4.1. *Preparing the MCA*

With the aim to further understand the characteristics of the users and how these are significant for sustainability, a more explanatory numerical analysis was applied. Since the user variables were dominantly categorical in nature, multiple correspondence analysis (MCA) was found appropriate.

To explain briefly, MCA starts with the assembly of a cross-table containing a set of variables with respective categorical selections. For example in Table 8, rows contain the observations of responding users and the columns contain the respondents' details for specific variables with corresponding categorical selections. From which, a multidimensional contingency table called the Burt matrix, which contains the frequency distribution of the variables, can be derived. MCA is then performed on this matrix, using the frequencies as weights for each variable and the variances defining the dimensions. Several dimensions are produced, where the 1st dimension explains the greatest deviation. Dimensions have centroids which can be imagined as the average of the profiles. The further a value is from the centroid the greater its importance in explaining the dimension. The significance of dimensions are explained by their inertias; for this paper, total dimension inertias ranging from 60% to 70% was assumed as the tolerable total inertia to explain the variances.

Generally, the variables investigated in the study pertained to the user behavior in consumption (PV power consumed and alternatives consumed) and user characteristics (monthly income, education level, occupation and # of residents in the household). Table 9 shows the categorical frequencies of these observed characteristics.

4.2. *MCA analysis of variables*

4.2.1. *Explaining the user attributes*

In order to analyze the relationship of users' attributes the following variables were used: electricity consumption, monthly income, number of residents, education level, occupation, and alternatives consumption. Fig. 8 shows the results of the user attributes MCA plots. Dimension 1 (53.1% inertia) explains a general tendency for the high electricity consumption, high income, high alternatives consumption, vocational/college educational level and business occupation to have similar inertia direction and intensities. There was also a general clustering of users with low income, low consumption, low alternatives consumption with elementary education and fishing occupation. Dimension 2 (9% inertia) explains a tendency for high income groups to

Table 8
Sample cross-table of PV system users' social conditions.

User ($n=50$)	Income level	Education	Number of residents	Occupation	PV power consumed	Alternatives consumed
1	Low (1)	Low (1)	Low (1)	Fishing (1)	Low (1)	High (3)
2	High (3)	High (3)	Ave. (2)	Service (2)	High (3)	Low (1)
3...50	Ave. (2)	High (3)	High (3)	Business (3)	Ave. (2)	Ave. (2)

Table 9
PV system users' attributes with categorical frequencies.

Attributes	Obs	Categories and Frequencies		
		Low	Middle	High
Income	50	25 (<PhP4000)	20 (PhP4000–7000)	5 (>PhP7000)
# of residents	50	5 (<4)	35 (4–6)	10 (>6)
PV power consumed	50	23 (<5 kWh)	18 (5–9 kWh)	19 (>9 kWh)
Alternatives consumed	50	24 (<PhP100)	20 (PhP100–150)	6 (>PhP150)
Education level	50	33 – Elementary	11 – High school	6 – Voc./college
Occupation	50	26 – Fishing	9 – Service	15 – Business

have lower number of residents while Dimension 3 (4.7% inertia) explains high alternatives consumption to be for high number of residents. Although not shown in this paper, an MCA conducted for income and occupation showed grouping tendencies for business with high income, services with medium income, and fishing for low income. An MCA plot for education and occupation showed grouping tendencies for vocational/college with business, high school with services, and elementary with fishing.

With the results of the MCA of user attributes it can be understood that consumption tendencies of users are related to the income, education, and occupation of the users. Better educated users engage in business activities which may translate to higher income. Higher income, better education, and business opportunities can explain higher consumption patterns both for PV electricity and alternative sources. If the community thus has better education and business opportunities, higher income and higher consumption of electricity may follow which then improves the plant's financial income.

4.2.2. Explaining the time and types of electricity usage

In the survey, users were asked what time they used electricity commonly during a 24-h period. Users marked a yes or a no on a 3-h interval selection. An MCA was conducted for the time of usage together with electricity consumption, monthly income, and occupation of users; shown in Fig. 9. Considering Dimension 1 (43.4% inertia), the high income, high electricity consumption, and business occupied groups were characterized with having used electricity majority of the time. The fishing, service and low-income groups clustered with mixed usage and non-usage in specific times. Considering Dimension 2 (17.9% Inertia), there is a clustering of the business and high consumption groups with usage during the 5–8 am – (when the day starts–) and 2–5 pm while having a distinct non-usage during the 5–8 pm time. It is observable in the frequency of usage, Fig. 4, that the 5–8 pm time has the most number of users. However, according to plant technical consultants, although power is available during this time, due to the high demand and low battery output, the power available is at a low voltage enough

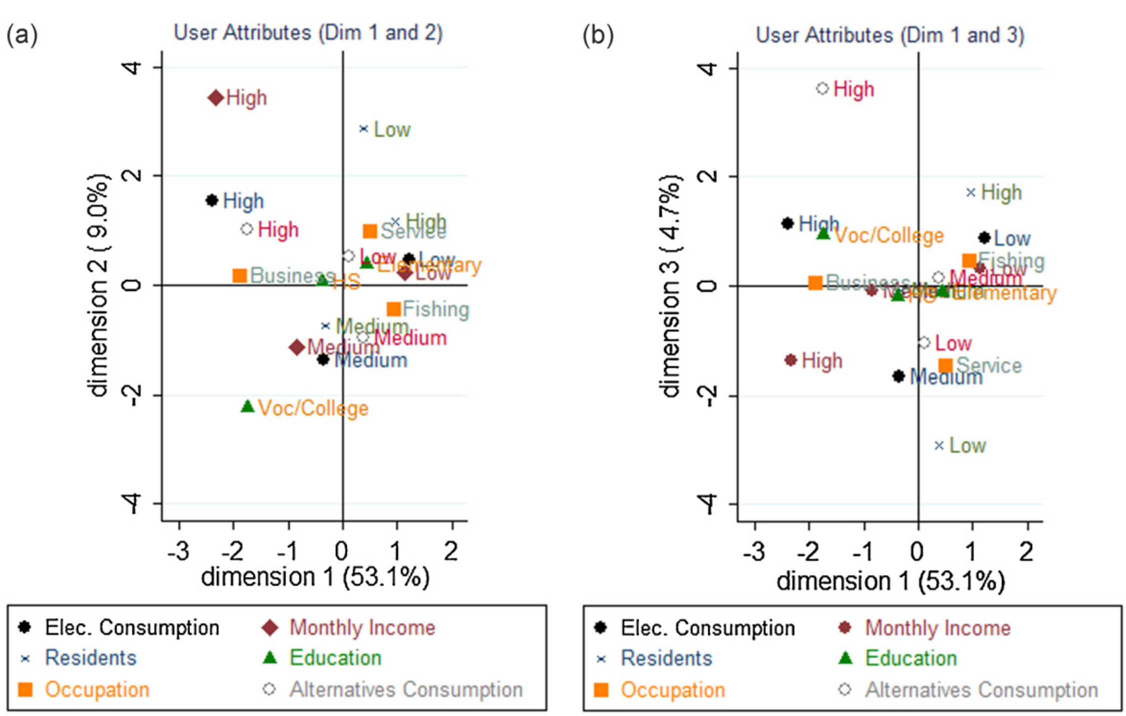

Fig. 8. MCA plot of PV users' attributes (a) dimensions 1 and 2 and (b) dimensions 1 and 3.

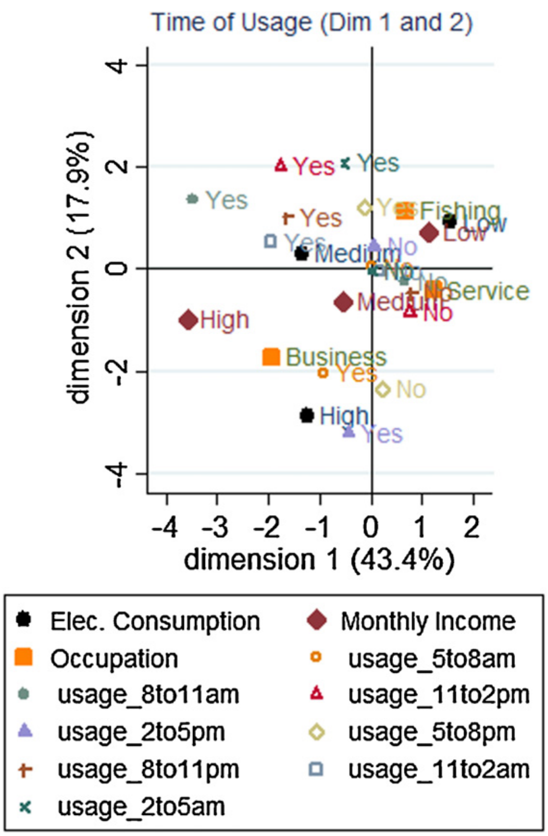

Fig. 9. MCA plot for time of electricity usage of PV system users.

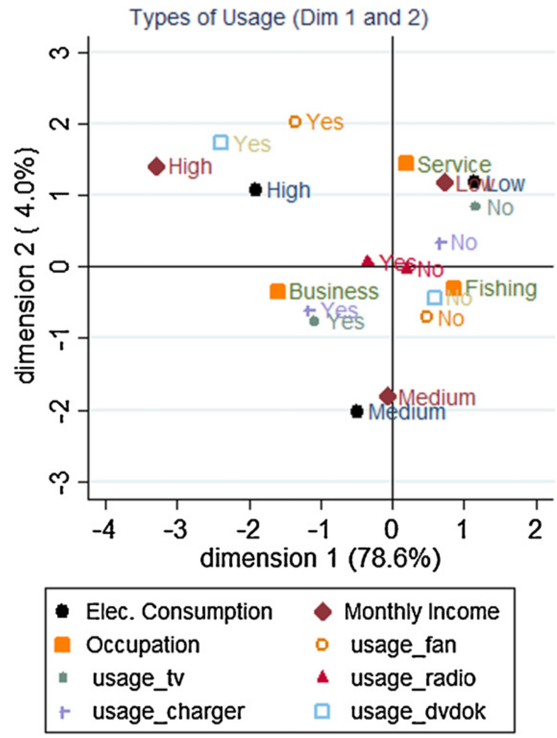

Fig. 10. MCA plot for type of electricity usage of PV system users.

only for small lights. This explains why high electricity consuming households could no longer use their desired power during 5–8 pm duration.

Users were also asked what type of appliances they would use electricity with. An MCA of the types of usage was conducted with the electricity consumption, monthly income, and occupation; shown in Fig. 10. It is verified that high income, high consumption and business groups favor the usage of fans, DVD/karaoke sets, phone chargers and TVs. The low-income service and fishing groups favor non-usage of the appliances and therefore use electricity mostly only for light, explaining their lower electricity consumption.

4.2.3. Explaining the satisfaction and priorities of users

In the survey, users were asked for their satisfaction levels and priority items for the household. Satisfaction levels ranged as low, medium and high for the following items: amount of electricity (refers to how many kWh they can use), availability of electricity (refers to the times or duration electricity is available), and affordability (refers to perception of electricity price). An MCA was conducted for Satisfaction levels together with electricity consumption, monthly income and occupation, as shown in Fig. 11. In Dimension 1 (54% inertia), the high income, high consumption, and business groups showed lower affordability satisfaction. With Dimension 2 (8.2% inertia), the high consumption groups tended to have lower amount satisfaction whereas low-income groups had higher amount and availability satisfaction. Results indicate that higher income and consumption users, usually with business activities, express less satisfaction about the electricity price. These groups are the ones paying more hence they feel the burden of the high PV price.

Priority of needs ranged as low, medium and high according to their perceived need for the following items: housing, electricity, food, water, education, and others. An MCA of the priorities was conducted together with electricity consumption, monthly income and occupation, as shown in Fig. 12. Items with "?" refer to instances with no answers from respondents and thus these items were treated separately automatically through MCA. Dimension 1 (77.4% inertia) does not show significant variances in the items. Dimension 2 (7.3% inertia) however shows that high income groups have high water priority, medium education priority and low electricity priority. High consumption and business users were also closer to this orientation, having low food priority. What can be understood is that with higher income, electricity significance got lower,

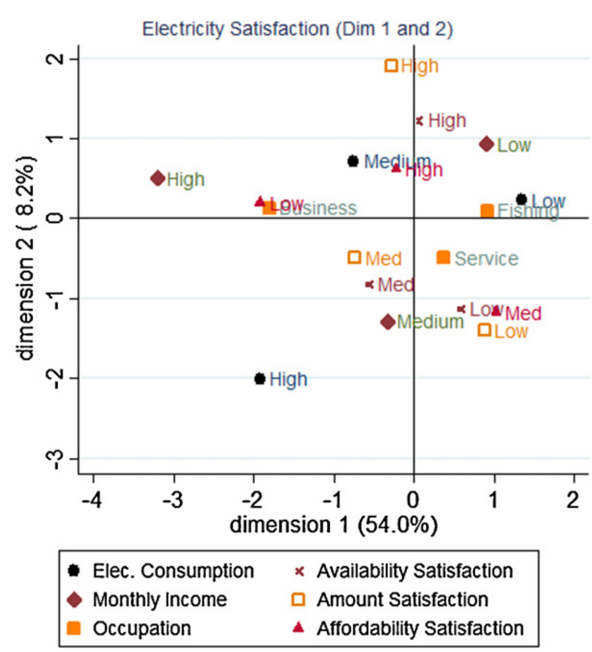

Fig. 11. MCA plot for electricity satisfaction levels of PV system users.

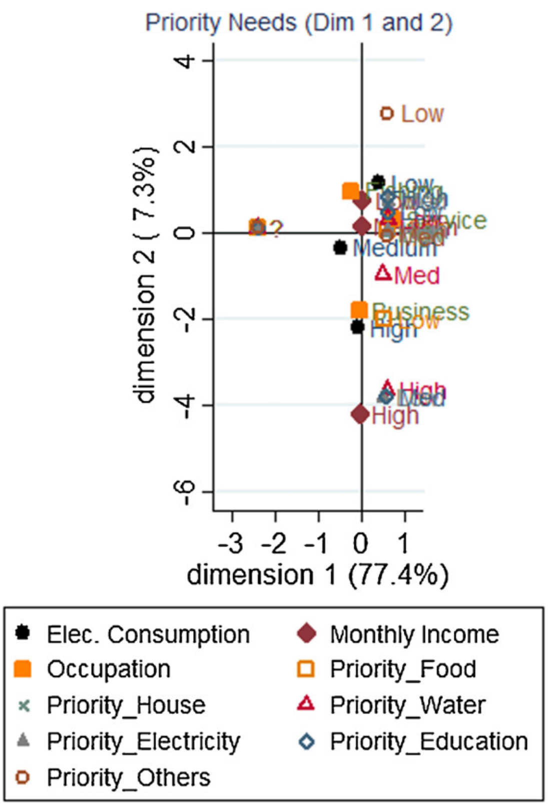

Fig. 12. MCA plot for priority needs of PV system users.

indicating that electricity was not very essential in their income generating activities, rather other items, such as housing, are more important.

5. Conclusions and recommendations

Applying renewable energy systems for rural electrification holds a great promise to improve energy access for the distant areas where energy is scarce. There are however several sustainability challenges related to technology, economics and the community which are important to consider. The rural community in Pangan-an Island was mostly users with low income and low education. With fishing as the main source of income, no significant economically lucrative activities using electricity was found to improve the people's ability to pay for electricity. Although the centralized PV system provides more reliable power at a reasonable cost compared to conventional sources, the obligation to have a monthly minimum cost is too much for some low-income users and thus discouraged connections. For a centralized PV plant, the number of connected households dictates the minimum cost per household to sustain the plant; including the replacement costs of the essential parts such as batteries for power storage. Thus, fewer connections meant a higher cost for connected users regardless of the household income or electricity consumption level. Since initial connections were few, the plant management was forced to adapt socialized prices, decreasing the price of power to accommodate low-income users. This further decreased the plant's financial viability. Similar questionable management decisions by the management proved that further capacity development and technical support is needed. Capacity development efforts however would cost more for the project, costs which could not be afforded without external support. Despite the high costs and decreasing plant efficiency, users were generally satisfied with the project and regarded electricity as important to their lives. The peoples' welfare improved through better lighting, especially for education, and usage of basic appliances such as television and radio. The continued decrease in plant efficiency, however, forced users to return to conventional power sources, which are less efficient and hazardous for health and the environment. Evidently, the expensive parts of the plant, such as the batteries, could not be replaced due to lack of funds. With these realizations, it is important to come up with new alternative and financially viable ways to extend the service life of this deteriorating plant. One possible economic way is by the use of rechargeable LED lamps to serve as secondary power storage, augmenting the inefficient plant batteries and providing light at night. End-of-life strategies for RESs are important to consider in promoting sustainability.

MCA was applied to various user attributes which correlate with user consumption behavior. It was found that higher consumption came about with higher income users with business as an income source and with better education. These groups were, however, less satisfied with the electricity price and had less priority for electricity compared to other needs; indicating that electricity is not as essential for income generation. Plant sustainability, however, relies on good electricity sales from these higher income users. If community development is to take place, higher education and business opportunities which use electricity are important to develop and support.

Overall, the sustainability challenges found in the Pangan-an Island Electrification Project display a practical perspective to further understand the fate of RES projects in rural applications. It was found that user attributes can help explain their consumption behaviors which may then be used as a basis to create appropriate plant capacity and pricing mechanisms sustainable for the community. In a centralized power system, the number of connections and household consumption levels greatly influence the affordability of electricity and viability of the plant. Capacity development and support that enable users to have commercially productive uses of electricity along with good institutional capacity to manage the power system all contribute to better sustainability of the project. A holistic and comprehensive approach in developing, monitoring, and maintaining RES projects can indeed contribute to a more sustainable and effective power provision system for rural communities.

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